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(54) SOLID FUEL PROPULSION UNIT

(72) We, DYNAMIT NOBEL AKTIENGESELLSCHAFT, a German Company, of 521 Troisdorf, near Cologne, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to a multi-chamber rocket propulsion unit.

Multi-stage propulsion units comprising a cylindrical housing in which there are disposed one behind the other two or more solid propellent bodies have a number of advantages over propulsion units which each have only a single propellent charge body. These stem from the fact that the total thrust provided by the propulsion unit is divided into two or more separate thrust phases. In practice, these thrust phases do not immediately succeed one another, but are separated by a thrust-free flight phase. It is possible to use different fuels and/or propellents for the propellent bodies intended to provide thrust during the launching and the cruising stages of the rocket. However, it is frequently also desirable to use the same propellent material for each of the propellent bodies used in the propulsion unit. By providing propellent bodies for a number of thrust phases in a propulsion unit, it is possible to provide a measure of thrust after launching, in a cruising stage, for overcoming the influence of the resistance of the air. Hence, under otherwise equal conditions, the range of the rocket is increased in relation to that of a single-chamber rocket. Finally, with multi-chamber propulsion units, the range can be more widely varied, because action can be taken to take individual propellent charges selectively out of the ignition. It is therefore possible to produce both short and long ranges for particular rockets and at the same time to keep the angle of impact relatively large in each instance. This last factor is important for target accuracy.

One problem which generally arises in multi-chamber propulsion units is that the burn-up of one first propellent charge must not spread in the headward direction to the next propellent charge. Hence all the propellent charges must be sequentially ignitable, without the burn-up of the first stage influencing, for example, the second stage.

One form of multi-stage rocket propulsion unit of the internal burner type is described in United States Patent Specification No. 2 956 401. In the propulsion unit, the individual hollow cylindrical propellent charges are isolated from one another by separators. The separators are formed therethrough with passages through which the gas pressure in the interior of the propellent bodies undergoing combustion can be balanced. Each of the sequentially arranged hollow cylindrical propellent charges is initially coated on its inner wall with an ignition charge and then with an inhibitor layer. The inhibitor layer also encloses an igniter acting on the ignition mass and is intended to prevent burn-up from spreading from a propellent body undergoing combustion to the neighbouring propellent. Such multi-layer propellent bodies are difficult, however, to manufacture. The propellent itself is processed under extremely complex safety precautions. The inhibitor layer must be very carefully united with the other layers. The smallest fault therein might nullify the action of the whole inhibitor layer. A further problem resides in the differing thermal behaviour of the various layers. Owing to the difference of the expansion coefficients of the inhibitor layer and of the propellent charge, cracks may be produced. Such cracking may also occur during the storage of the rockets or of the propellent bodies for use therein. In addition, the inhibitor layer takes up a considerable amount of space, which might otherwise be used to accommodate the fuel. Finally, inhibitors are generally thermoplastic materials which must be rather thickly applied and which readily volatilise.

In our British Patent Specification No. 14497/73 (Serial No. 1 428 411) the aforesaid disadvantages are met by providing a solid partition between the propellent bodies so that they are each located in clearly defined chambers. During the burn-up of one propellent body, the body is isolated in gas-tight manner from propellent bodies on the head-ward side thereof so that combustion gases are prevented from spreading to further propellent bodies. The partition is formed with apertures which are closed with plugs to make them gas-tight. In a second thrust phase, the plugs are forced out through the nozzle(s) of the rocket by combustion gases from the second stage so that the

gases can escape through the partition. Such a partition is relatively heavy and therefore increases the weight of the propulsion unit, and in fact reduces the range of the rocket, the range-reducing effect increasing with the number of thrust phases to be provided by the propulsion unit. A further disadvantage of a pressure-sealing partition is the cost of manufacture.

According to the present invention, there is provided a solid fuel rocket propulsion unit which comprises two or more sequentially and coaxially arranged combustion chambers each housing a solid propellent body, each operating on a common nozzle and each of which is fitted with a firing device for firing the bodies in the respective chambers at different time intervals, at least two said chambers being separated by separating means in which is provided or at which commences and extends in the head-ward direction in a cavity extending lengthwise of the propellent body on the head-ward side of the separating means, cooling means which allows gas-flow therethrough in the axial direction, whereby the thermal content of gases produced on the nozzle-ward side of the separating means, in use, is transmitted to said propellent body in insufficient amount to cause ignition thereof.

With a rocket propulsion unit embodying this invention, there is no need to provide a heavy gas-tight partition between successive propellent bodies. It is also unnecessary to produce propellent bodies having a multi-layer construction. A pressure equalisation now takes place between the burning propellents at the nozzle side of a propellent transition zone and the propellent or propellents which are not yet burning at the head side thereof. After ignition of a propellent at the nozzle side of the transition zone, a uniform pressure is set up throughout the housing of the propulsion unit, because the part or parts of the combustion chamber at the head end or side of the transition zone are open only towards the propellent body or bodies on the nozzle side thereof. It must here be borne in mind that, owing to the fact that there is only a small free volume between the propellent body or bodies on the head side of the transition zone, only a relatively small amount of combustion gas passes into the region of the propellent body or bodies on the head side of the transition zone and that this small quantity must in all circumstances pass through the cooling means provided therefor, preferably in the transition zone.

The intensity of the cooling which must be effected by the cooling means depends upon the conditions in each particular case. The temperature at which the burning of double-base solid fuels is initiated is usually 430° – 400°K, and in the case of composite fuels it is about 570°K. The initiation of the burning of a propellent body can be prevented with certainty if no point on the surface of the propellent body is able to achieve such temperatures. The necessary cooling can be effected for example by chemical means by capacitive heat dissipation, or by a combination of both these cooling modes.

The expressions "chemical means" or "chemical cooling" used herein mean that substances can be used to provide a cooling effect if they undergo thermal decomposition endothermically or if they can vaporise or sublime and thereby produce a cooling effect. These substances are herein termed "coolants" or "cooling substances". The term "capacitative heat dissipation" is used to indicate simple direct heat transfer to a member able to absorb heat or conduct heat of propellent gases away from the burning surface of a propellent body to be subsequently ignited.

In a preferred form of propulsion unit embodying this invention, there is secured in an aperture in a partition member separating the propellent bodies a container which is gas-permeable at least at transverse surfaces defining its ends and in which there are disposed one or more cooling elements which consist of or are provided with cooling material and which form a gas-permeable structure.

The gases escaping from the nozzle end combustion chamber are then able to pass through the container into the head-end combustion chamber, undergoing cooling as they pass through the cooling members. The cooling members may be constructed, for example, as cylinders or as spheres. They can contain as coolant a material which decomposes endothermically, for example ammonium bicarbonate or ammonium oxalate. These substances may be directly pressed into the form of cooling bodies, for example from a mass of powder. The strength of the cooling bodies may be increased by a proportion of up to 5% by weight of binding agent. Examples of binding agents which can be used are thermoplastic synthetic resins or cross-linked synthetic resins. The cooling bodies may be adhesively secured in the container by means of a bonding agent.

The cooling bodies, if cylindrical, may possess constant cross-sectional profiles over their length. They are then preferably produced by extrusion or by other pressing methods. It is also possible to use in the container only one cooling member which has a uniform cross-sectional profile throughout, and which allows combustion gases therethrough, for example a honeycomb structure.

Instead of using a mass of cooling substance as cooling means, it is possible to use a carrier structure coated with cooling substance. The carrier may be of laminar or grid or lattice form, or it may be constructed as a supporting body of any desired shape. The carrier may consist, for example, of waxed pasteboard or aluminium. The cooling substance may be applied to the carrier by spraying, foaming thereover, pouring thereon or spreading thereover.

A preferred feature a propulsion unit embodying this invention has is that the cooling means, for example the container permeable at its ends and containing the cooling members, can be produced and fitted as a separate part without any special safety precautions. The container and the cooling members can be of relatively light weight, and the partitions or supports necessary for fixing them in the propulsion unit need not be of high strength, because they only have to withstand low gas pressures.

In order that a container as aforesaid may be accommodated in the transition zone between two propellent bodies (or even predominantly in one of the propellent bodies), it is desirable for at least one of the propellent bodies to be formed with an axial recess into which the container projects.

When internally burning propellent bodies are used, especially burners of the radial type, it may be desirable for the propellent bodies to be milled or drilled out in accordance with the diameter of the container. This machining can be carried out without any particular hazard.

In order to obtain a maximum surface of cooling substance in the available container space, it is preferred to coat the walls of the container with cooling substance, irrespective of the form of cooling bodies used. Coating of the container wall may be effected by spraying, foaming or pouring or by the application of a preformed film of cooling substance to the walls of the container. The cooling substance applied to the walls of the container need not necessarily be an endothermically decomposing chemical, but may be, in contrast, metallic heat-dissipation means, for example a copper or an aluminium gauze. The thermal dissipation may take place towards the external surface of the propulsion unit.

It is not at all essential for the cooling means always to be provided in the form of a solid body. It is also possible to employ a pulverous or a liquid cooling medium in a ring-shaped container disposed between the propellent bodies. The aperture in the ring-shaped container enables pressure equalisation to occur between the two chambers of the propulsion unit separated thereby. If desired, a perforated plate or a resilient diaphragm, through which the pressure equalisation can take place may be provided in the aperture, at the nozzle end of the ring-shaped container. On firing of the head-end propellent body, these parts and the cooling substance container are destroyed.

The ring-shaped container preferably has a nozzle-shaped throughflow passage for concentrating gas flow therethrough and the wall of which is formed with at least one ejection opening. When gases flow through the said passage, the cooling means situated in the ring-shaped container is entrained and vaporised or decomposed. In the mounting of the propulsion unit, the ejection opening may be sealed by a covering or strap of thermoplastics material. The said strap may have the form of a flap valve. Either a single ring-shaped nozzle having an ejection opening may be provided or the container lying across the propulsion unit may comprise a number of separate ejection openings directed at an angle to one another. To assist in the imparting of spin to the propulsion unit, the ejection openings may blow the cooling means into the flow channel at an angle to the longitudinal axis of the latter.

In a further form of propulsion unit embodying this invention, metal cooling plates are provided in the neighbourhood of the fuel surface to be protected. In this case, no cooling arrangement is required in the transition zone of the propellent bodies. The end surfaces thereof will be insulated in conventional manner and propellent gases will be free to enter the internal cavity in the head-end propellent body. In place of the cooling plates plastics foils coated with cooling substance or metal foils may be used in the cavity of the propellent bodies to be protected. The cooling arrangements must not in any circumstances impede the expansion of the gases in the axial direction. In addition, the cooling arrangements should not be fixedly connected to the propellent body in which they are disposed but at most lie loosely against it.

The covering plates are preferably so shaped at their ends closer to the head that the hot gases produced by an igniter provided on the propulsion unit at the head end for the propellent body thereadjacent flow predominantly between the covering plates and the fuel surface to be ignited. The covering plates thus both protect the fuel surface of the propellent body to be protected from the hot gases from the nozzle-end propellent body and, in addition, promote the subsequent ignition of the protected propellent body.

A particularly simple form of cooling means which can be used in a propulsion unit embodying this invention is constituted by cooling matter of large surface area introduced loosely into the cavity of an internal-burning propulsion charge in order to effect the necessary protection by cooling. For example, cooling wadding, cooling tinsel or cooling foam.

One further means of carrying the invention into effect involves providing between successive propellent bodies a preferably resilient, gas-permeable separating layer comprising a capacitive or chemical coolant means. The separating layer may alternatively contain metal plates in the form of dished springs haveing such cooling means. Owing to its resilient properties, the separating layer makes it possible to achieve thermal length equalisation and thus prevents the production of inadmissible thermal stresses as a result of expansion during the storage of the rocket propulsion unit, in addition to the desired cooling effect. Preferably the separating layer disintegrates on burn-up of the

head-end propellent body, to yield small fragments which pass out through the propulsion unit nozzle without damaging it.

A particularly favourable effect in the prevention of burn-up of a second or subsequent propellent body is obtained if the cooling means employed additionally contains a substance which can be endothermically decomposed when it liberates a heat-retaining powder which becomes firmly lodged on the nozzle end wall of the combustion chamber. Since this powder forms, in effect, an insulating layer on the wall of the combustion chamber and thus cools it, is is possible for the wall to be made substantially thinner than otherwise.

It is pointed out that although the present invention is generally described herein with respect to the use of only one type of cooling means in a propulsion unit embodying this invention, combinations of different types of cooling means can be used. Thus, for example the plate-forming cooling members which may act like cooling fins in star-shaped cavities, or wadding or tinsel having a baffle-effect can be used in combination with resilient cooling means provided between the propellent bodies.

It is further pointed out that the terms "nozzle side or end" and "head side or end" used herein are not limited to the propellent bodies immediately adjoining the nozzle and the head of a rocket fitted with the propulsion unit, but in the case of a propulsion unit having three or more propellent bodies which have to be sequentially ignited, it also includes the propellent bodies situated therebetween and a particular reference position.

For a better understanding of this invention and to show how the same can be carried into effect, reference will now be made, by way of example only, to the accompanying drawings, wherein:

Figure 1 shows a two-chamber rocket propulsion unit embodying this invention in longitudinal section;

Figure 2 is a transverse cross-section along the line II-II of Figure 1;

Figure 3 shows, in longitudinal section, part of a second form of rocket propulsion unit embodying this invention;

Figure 4 is a transverse cross-section along the line IV-IV of Figure 3;

Figure 5 is a similar view to that shown in Figure 3 of part of a third form of propulsion unit embodying this invention;

Figures 6 and 7 are transverse sections through further forms of propulsion unit embodying this invention; and

Figure 8 is a longitudinal section through a final form of rocket propulsion unit embodying this invention.

Referring to Figure 1, a rocket propulsion unit embodying this invention comprises a cylindrical housing 10, at one end of which there is provided a nozzle 11, and the other end 12 of which serves for the mounting of a rocket head.

The cylindrical housing 10 is subdivided into two sequential combustion chambers axially in line with one another, one of which contains a nozzle-end propellent body 13 and the other a head-end propellent body 14. The two propellent bodies are shaped to operate as radial internal burners, that is, they are of elongate shape, are externally cylindrical and have a continuous internal cavity 15 whose shape may vary but which is preferably of star-shaped cross-section, as is shown in Figure 2, or, more clearly, in Figure 6. Star-shaped radial internal burners have the advantage that their burning area is relatively large throughout the burning period. They may be so designed that the burn-up area is substantially constant as a function of time. Radial internal burners of star-shaped internal section enable a combustion chamber to contain a particularly large amount of propellent.

Disposed between the propellent bodies 13 and 14 and the housing 10 are insulating layers 16 formed for example, of ethyl cellulose and which are intended to prevent thermal overloading of the housing itself. The insulating layers 16 terminate at the outer ends of ring-shaped propellent holders 17 and 18, which are set into the propellent bodies at their external peripheries, and which ensure that the propellent bodies are held in place between the nozzle 11 and the head end 12. The insulating layers 16 are bent over inwards at the inner ends of the propellent bodies 13 and 14 and here lie, in the form of end flanges 19, on the propellent bodies.

Situated between the end flanges 19 and spaced apart therefrom is a thin partition 20, which is secured to the wall of the housing 10 and subdivides the housing into compartments. The partition has a central aperture in which a tubular container 21 (see Figure 2) is disposed coaxially with the housing 10. The ends of the container 21 are constituted by perforated plates 22 and 23 which may be formed or metal or plastics material. The cylindrical container wall may be formed of metal, plastics or other material.

The container 21 projects axially into each of the two propellent bodies 13 and 14, which are formed with cylindrical recesses 24 produced by milling.

As can be seen from Figure 2, the container 21 is filled with cylinders 25. These contain a cooling substance, and preferably extend from one end plate 22 to the other end plate 23. The cooling substance is a substance which decomposes endothermically on heating, for example ammonium oxalate, ammonium bicarbonate or oxamide. The cooling substance may be admixed with a binding agent prior to forming into cylinders 25, or a cylinder thereof may possess satisfactory strength. The cylinders 25 should have a large surface in relation to their volume. Hence, it is preferred to place thin

cylinders in contact with each other providing, in effect, needles of cooling substance. Alternatively, the cylinders 25 may consist of carrier bodies which are externally coated with cooling substance. A particularly light form of cylinder 25 is obtained if it is formed as a grid structure consisting of an extruded mass of cooling substance, which allows passage of gas therethrough in the axial direction.

In fact, the container 21 may be filled with a mass of cooling substance in spherical or granulated form so as to allow passage of gas therethrough in the axial direction in all circumstances. Therefore, sufficient cavities must be present between the individual bodies of cooling substance. The walls of the container 21, and, when a supporting structure is employed therein, the wall compartments of the supporting structure, may be coated with a cooling foam, the layer thickness of which is, for example, 2 mm.

As an alternative to the use of cooling substances as aforesaid, it is possible to work with liquid cooling substances having high thermal capacity, for example water, and/or high vapour pressure, for example the refrigerant Frigen (Registered Trade Mark). Preferably, the liquid cooling substance is a chloro-fluoalkane which is liquid at the storage temperature of the propulsion unit and which has as low a saturation pressure as possible. Liquids of high vapour pressure volatilitise very quickly when heated by the propellent gases of the nozzle-end propellent body 13 and can reduce or entirely suppress the flow of further hot gases into the chamber containing the head-end propellent body 14 by producing a "pressure barrier". In this way, the cost of coolant can be reduced in some cases.

The operation of the propulsion unit of Figures 1 and 2 is as follows. After the ignition of the propellent body 13 by a propellent igniter 26 accommodated with a retaining means in the nozzle 11, the pressure in the combustion chamber containing the propellent body 13 rises, and consequently hot gases flow through the container 21 into the combustion chamber containing the propellent charge 14. Air in the combustion chamber containing propellent body 14 becomes compressed and mixed with propellent gases from the combustion chamber containing the propellent body 13. These propellent gases are cooled to such an extent in passing through the cooling container 21 that their temperature is below the initial burning temperature of the propellent body 14 when they make contact therewith. After burn-up of the propellent body 13, the pressure in the two combustion chambers falls, and a return flow of gas through the container 21 takes place.

When thereafter the propellent body 14 is ignited by means of a head-end igniter 27, the last residues of the contents of the housing 21 are ejected through the nozzle. The perforated end walls 22 and 23 are destroyed or burnt out, so that, as the head-end propellent body 14 burns up, expansion of the burning combustion gases produced thereby through the nozzle 11 is ensured. In some cases, the container 21 may remain intact, with or without its end walls 22 and 23, during the burn-up of the propellent body 14.

Referring next to Figures 3 and 4, in which like reference numerals represent like parts in Figures 1 and 2, the same propulsion unit housing 10 is employed as in Figures 1 and 2 and the partition 20 is again provided in the same position and in the same form. However, the container 21 is not secured in the partition 20 along a central plane therethrough but at one end, so that it projects substantially over its entire length into the propellent body 14 to occupy a recess 24′ of suitable length therein.

The ends of the container 21 are open, with the exception of ring-shaped holders 28 which secure against displacement a coil 29 of cooling substance which is disposed in the container 21. The coolant spiral 29 consists of a thin foil of a cooling substance whose width is substantially equal to the length of the container 21 and which is spirally coiled.

The forms of propulsion unit described hereinabove with respect to Figures 1 to 4 may be varied. Thus, it is possible to use a container whose cross-section is not circular, but is adapted to the internal profile of the propellent bodies. In this case, the container has a large surface area in the longitudinal direction with a comparatively small cross-sectional area of flow. Hence considerable cooling of the inflowing hot gases is achieved by the container wall alone. This form of container has the additional advantage of requiring little space and makes it, possible to avoid having to reduce the propellent content of combustion chambers of rocket propulsion units.

If the extent of cooling which is required is small, the container may be replaced by a grid formed into a tube which may itself act as a supporting structure for a solid coolant sprayed thereon in the form of a powder.

Referring next to Figure 5, there is shown the section of a propulsion unit at which two propellent bodies 13 and 14 are separated from one another by a space 31 between end flanges 19 of insulating material. Situated in the space 31 is a ring-shaped container 30 for a solid or liquid coolant which is coaxial with the propellent bodies and surrounds a nozzle-shaped passage 32. A solid coolant will be in a powder form and can be one of the aforesaid endothermically decomposable substances or a sublimable substance. As liquid can be used simply water, or ethylene glycol (for prevention of freezing). The container 30 has attached to its nozzle-end wall a perforated plate or resilient diaphragm 33. The resilient diaphragm may consist of aluminium foil, plastics or paper. The nozzle-end wall of the container 30 is con-

structed to open or yield as soon as a negative pressure is set up within the container 30 or at the nozzle-end side (i.e. nozzle mouth) of the nozzle passage 32.

There is provided in the nozzle passage 32 an undercut portion or step 34 ending in a flat section having a plastic covering flap 35, which thus closes a ring-shaped channel. Instead of providing a single nozzle passage 32 formed in this way, it is possible for a number of smalller nozzles of similar form to be arranged in ring formation. Pairs of diametrically opposed nozzles may be directed at an acute angle to one another in order to improve the atomisation of the coolant. Provision may also be made for the injection of coolant in a tangential direction into the chamber containing propellent body 14 to produce a spin, because the coolant is then thrown out radially, from the outlet of the coolant container 30, against that surface of the propellent body 14 which is to be cooled. In the form of arrangement illustrated in Figure 5, the nozzle mouth extends into a frustroconical recess 36 in the propellent body 14. (It will be recalled that the body 14 has an internal recess of star-shaped cross-section in preferred practice).

The arrangement of Figure 5 operates as follows. When the nozzle-end propellent has been fired, some of the combustion gases produced thereby flow through the nozzle passage 32 which constricts the gas flow. Owing to the negative pressure set up at the step 34 and the heating effect of the gases, the plastics covering 35 is opened, so that the coolant is entrained by the jet of gas. A diaphragm 33, when present, is opened by the native pressure set up in the interior of the cooling housing 30, so that the escape of coolant at the nozzle 34 is not hindered. A similar effect is achieved by perforations when a perforated plate 33 is used.

The arrangement shown in Figure 5 provides a particularly effective way of cooling the propellent body 14 since it enables the entire quantity of coolant to be atomised during the pressure build-up phase of the nozzle-end side propellent body 13, which has a large surface. The arrangement is therefore expected to be of particular value when the initial burning temperature of the hed-end propellent 14 is relatively low or where the head-end air volume is relatively large. The fixed walls of the container 30, that is those walls which are not destroyed during cooling of the propellent body 14, may be so designed that they are destroyed or burnt on firing of the propellent body 14. They may be formed of polyvinyl-chloride or of thin sheet metal, which may have been surface-treated.

In Figure 6 there is shown a section taken through the head-end propellent body 14 in the interior of the housing 10 of a propulsion unit of the type shown in Figure 1. The propellent body thus comprises an axially disposed cavity 15 shown here clearly to be star-shaped and which defines the inner contour of the propellent body 14. The nozzle-end propellent body and the head-end propellent body are each insulated at their ends, but gas can pass from one cavity into the other. From the transition between the two propellent bodies, extend cover plates 37 in the head-end direction to cover the internal surface of the head-end propellent body 14. In this way, on firing of the nozzle-end propellent, hot gases penetrate into the head-end air space, that is the cavity 15 but the surface of the head-end propellent body 14 is protected from the thermal effect of the gases by the cover plates 37, which are also of star form. The cover plates 37 do not bear directly against the propellent body at any point. At the bases of the arms of the star are situated thermally insulating distance pieces 39, which prevent direct contact between the cover plates 37 and the inwardly projecting tips of the fuel contour.

The igniter of the head-end propellent body 14 (shown at 27 in Figure 1) is preferably so constructed that its ignition gases are directed between the internal surface of the propellent 14 and the cover plates 37. In order that the nozzle 11 of the propulsion unit (see Figure 1) should not be endangered by the outwardly flying parts of the cover plates 37, which may consist of aluminium, steel or plastics, the cover plates 37 should not be very thick. If the cover plates 37 are made of plastics, for example, it may be necessary to inhibit the melting of the cover plates by entering hot gases of the nozzle-end propellent with the aid of cooling substances applied thereto. Hence the cover plates 37 may have a grid structure to which coolant is applied as hereinbefore described.

A particularly simple for of cooling arrangement for a propulsion unit embodying this invention is shown in Figure 7, in which the cavity 15 of the head-end propellent body 14 is filled by a cooling mass 40 which is gas permeable and consists, for example, of wadding and coolant in combination with a binding agent. Alternatively, the cooling mass may comprise a foam body inserted or injected into the cavity 15. Situated at the nozzle-end of the propellent body 14 and not shown in the drawing is a thermal insulation which, on burn-up of the nozzle-end propellent body 13, prevents the head-end propellent body 14 from being heated up.

It may be desirable to add to the cooling mass 40 potassium perchlorate ($KClO_4$), because this substance decomposes endothermically and the product of decomposition, i.e. oxygen (O_2) and potassium chloride (KCl), are desirable. Experiments in which potassium perchlorate was blown into a solid-fuel rocket combustion chamber have shown that some of the liberated potassium chloride adhered firmly to the walls of the combustion chamber and formed thereon a thermal insulating layer. This layer protected the walls of the combustion chamber of the

nozzle-end propellent body which had already burnt up, so that these walls can thus be made thinner and hence lighter by the use of potassium perchlorate or of another substance having a similar action.

Finally, referring to Figure 8, there is shown an arrangement in which a holder for the cooling device is not required. The two propellent bodies 13 and 14 are accommodated in a single continuous combustion chamber, which does not contain a fixed partition. Situated between the propellent bodies is a resilient separating layer 41 which serves to cool down the penetrating gases and to yield resiliently to the thermally induced changes in length of the propellent bodies 13 and 14 during the storage of the rocket motor. The separating layer 41 may consist, for example, of metal wire matting, formed for example of copper, a metal gauze fabric or of resilient gas-permeable distance plates. Plate springs can also be used for this purpose. The separating layer may additionally be coated with a coolant. It should then preferably have as large a surface as possible.

WHAT WE CLAIM IS:

1. A solid fuel rocket propulsion unit which comprises two or more sequentially and co-axially arranged combustion chambers each housing a solid propellent body, each operating on a common nozzle and each of which is fitted with a firing device for firing the bodies in the respective chambers at different time intervals, at least two said chambers being separated by separating means in which is provided or at which commences and extends in the head-ward direction in a cavity extending lengthwise of the propellent body on the head-ward side of the separating means, cooling means which allows gas-flow therethrough in the axial direction, whereby the thermal content of gases produced on the nozzle-ward side of the separating means, in use, is transmitted to said propellent body in insufficient amount to cause ignition thereof.

2. A propulsion unit as claimed in Claim 1, in which said cooling means is produced separately from and is accommodated in the propulsion unit separately from the said propellent bodies.

3. A propulsion unit as claimed in Claim 1 or 2, in which said separating means comprises a partition member separating the combustion chambers and having secured therein a container which is adapted for gas flow therethrough in the axial direction and which contains at least one cooling member allowing gas flow through the container.

4. A propulsion unit as claimed in Claim 3, in which said cooling member(s) is/are of constant cross-section in the lengthwise direction.

5. A propulsion unit as claimed in Claim 3 or 4, in which said cooling member(s) is/are constituted by a shaped mass comprising a cooling substance as hereinbefore defined.

6. A propulsion unit as claimed in Claim 3 or 4, in which the or each cooling member is constituted by a carrier structure coated with a cooling substance as hereinbefore defined.

7. A propulsion unit as claimed in Claim 6, wherein the carrier structure has a grid formation.

8. A propulsion unit as claimed in any one of Claims 3 to 7, wherein the internal wall of said container has a covering of a cooling substance as hereinbefore defined.

9. A propulsion unit as claimed in any one of Claims 3 to 8, wherein said container projects into an axial recess formed in a propellent body in at least one of said two chambers.

10. A propulsion unit as claimed in any one of Claims 5, 6 and 8, in which the said cooling substance is a compound which is capable of endothermic thermal decomposition.

11. A propulsion unit as claimed in Claim 1 or 2, in which a container of annular shape and containing a cooling substance as hereinbefore defined which is a liquid or powdered substance is disposed between said two propellent bodies.

12. A propulsion unit as claimed in Claim 11, wherein a plurality of said containers are disposed between said propellent bodies.

13. A propulsion unit as claimed in Claim 12, wherein said containers are themselves arranged in a ring.

14. A propulsion unit as claimed in Claim 13, wherein opposite containers around said ring are directed at an acute angle to each other in the headward direction of the propulsion unit.

15. A propulsion unit as claimed in any one of Claims 11 to 14, in which the or each said container comprises a covering flap which can be lifted by negative pressure at the nozzle-end side of the container to allow entrainment by gas passing into the combustion chamber on the head-ward side of the container of said substance therein.

16. A propulsion unit as claimed in Claim 15, when appended to Claim 11, wherein the flap is provided in an undercut portion of the internal periphery of the container.

17. A propulsion unit as claimed in any one of the preceding claims, wherein said cooling means comprises capacitative heat dissipation means as hereinbefore defined.

18. A propulsion unit as claimed in Claim 17, wherein the heat dissipation means is covered with a substance which is capable of endothermic thermal decomposition.

19. A propulsion unit as claimed in Claim 17 or 18, wherein a gas-permeable separating layer having the function of a capacitative heat dissipation means as hereinbefore defined or comprising a cooling substance as hereinbefore defined is disposed between the propellent bodies.

20. A propulsion unit as claimed in Claim 19, wherein said cooling substance is capable of endothermic thermal decomposition.

21. A propulsion unit as claimed in Claim 19 or 20, wherein the separating layer is resilient.

22. A propulsion unit as claimed in Claim 17 or 18, wherein gas permeable metal plates having a cooling effect are provided between the propellent bodies.

23. A propulsion unit as claimed in Claim 22, wherein said metal plates are plate springs.

24. A propulsion unit as claimed in Claim 10, 18 or 20, wherein said substance is ammonium oxalate, ammonium bicarbonate or oxamide.

25. A propulsion unit as claimed in any one of the preceding claims, which comprises propellent bodies of the internal burner type, having internal cavities extending therethrough, and in which said cooling means extends through the cavity in the propellent body in the head-ward side of the separating means and is shaped in the same manner as the contours of said cavity.

26. A propulsion unit as claimed in Claim 25, in which the cooling means is formed of plates constrained to lie out of contact with propellent material.

27. A propulsion unit as claimed in Claim 26, in which said plates are constructed as capacitative heat dissipating means as hereinbefore defined.

28. A propulsion unit as claimed in any one of the preceding claims, in which the propellent bodies have star-shaped cavities extending axially therethrough.

29. A propulsion unit as claimed in any one of the preceding claims, in which the propellent bodies have cavities extending axially therethrough and the propellent body on the head-ward side of the separating means contains as cooling means in the cavity therein, wadding, tinsel or powder having a capacitative heat dissipation effect on hot gases by which it is contacted.

30. A propulsion unit as claimed in any one of the preceding claims, wherein said cooling means comprises a substance capable of endothermic thermal decomposition to yield a heat retaining powder which coats, in use, the wall of the chamber on the nozzle side of the separating means.

31. A propulsion unit as claimed in any one of the preceding claims, wherein said separating means is constituted by thermal insulation means wrapped around the propellent bodies and extending over the end surfaces thereof.

32. A solid fuel rocket propulsion unit, substantially as hereinbefore described with reference to, and as shown in, Figures 1 and 2, 3 and 4, 5, 6, 7 and 8 of the accompanying drawings.

HASELTINE, LAKE & CO.,
Chartered Patent Agents
Hazlitt House
28 Southampton Buildings
Chancery Lane London WC2A 1AT
Also
Temple Gate House, Temple Gate,
Bristol BS1 6PT
And
9 Park Square, Leeds LS1 2LH, Yorks
Agents for the Applicants

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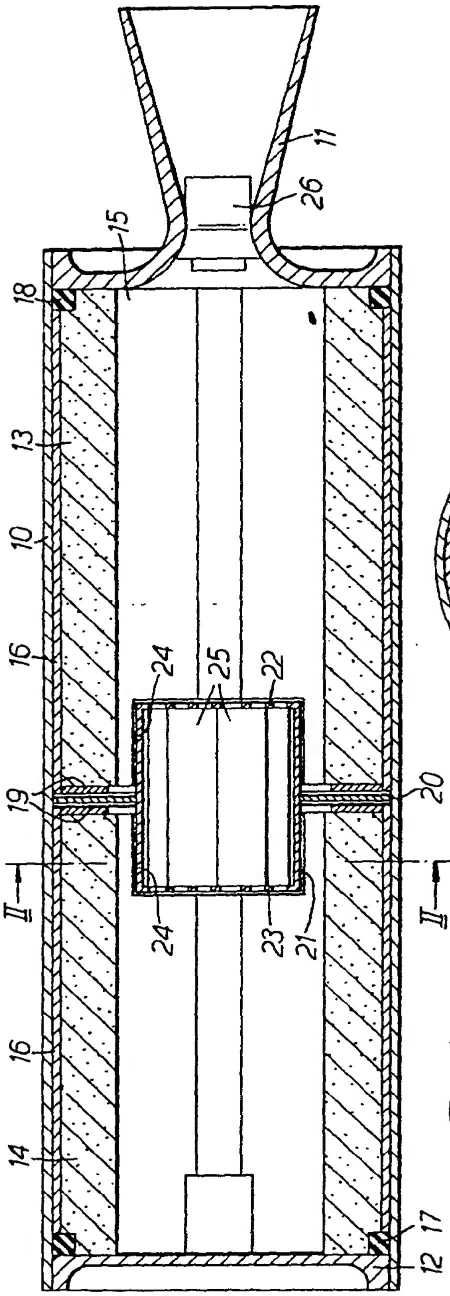
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FIG. 1.

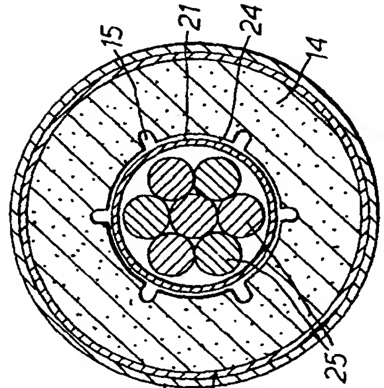
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FIG. 2.

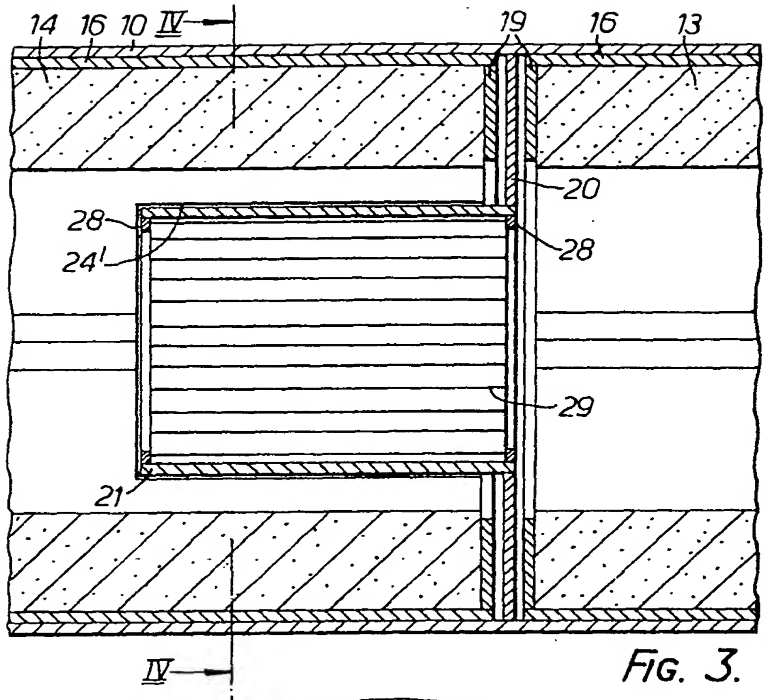

FIG. 3.

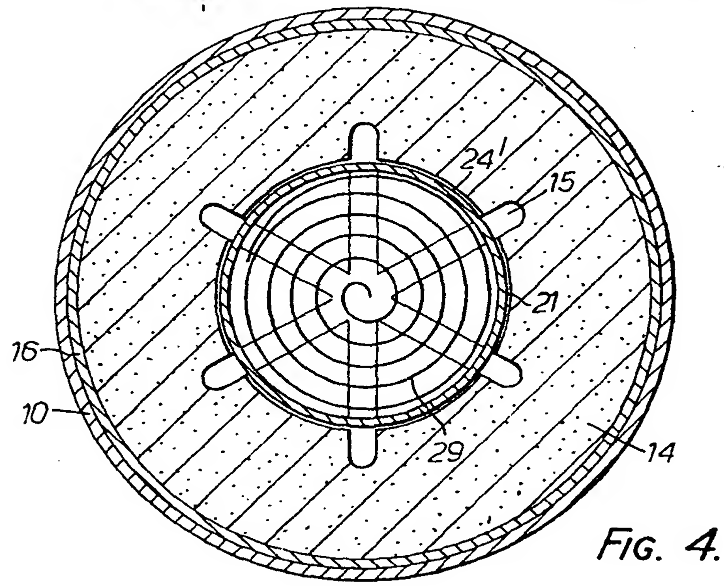

FIG. 4.

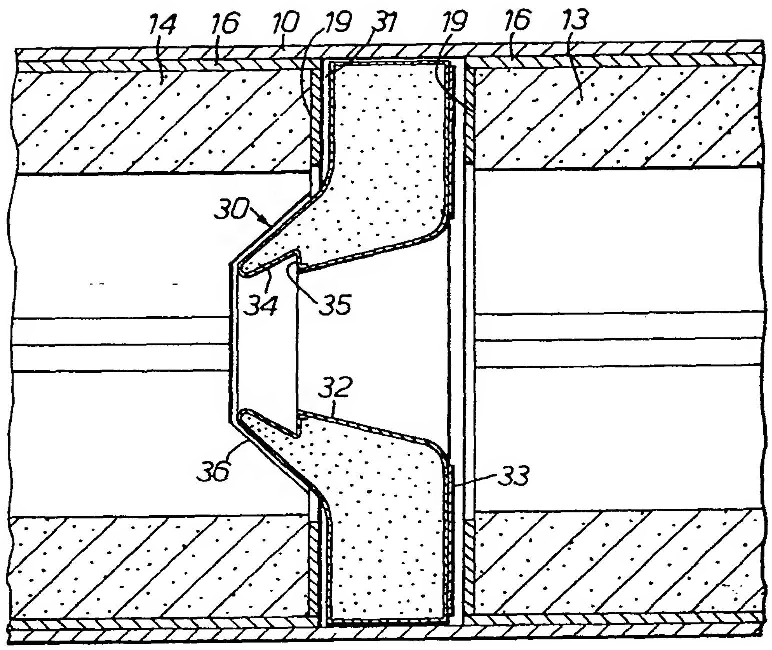

FIG. 5.

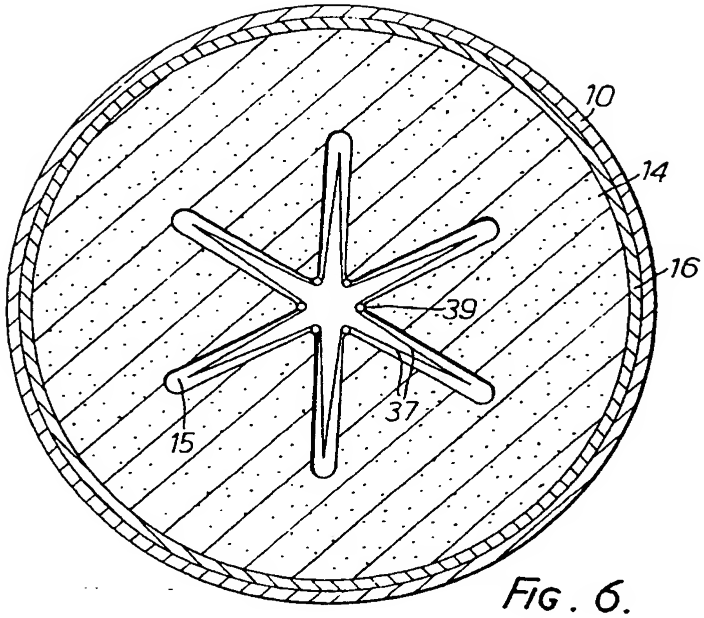

FIG. 6.

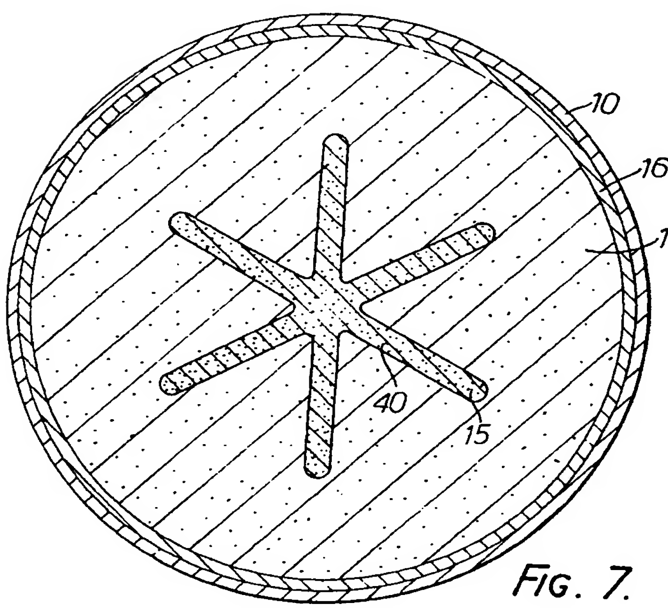

FIG. 7.

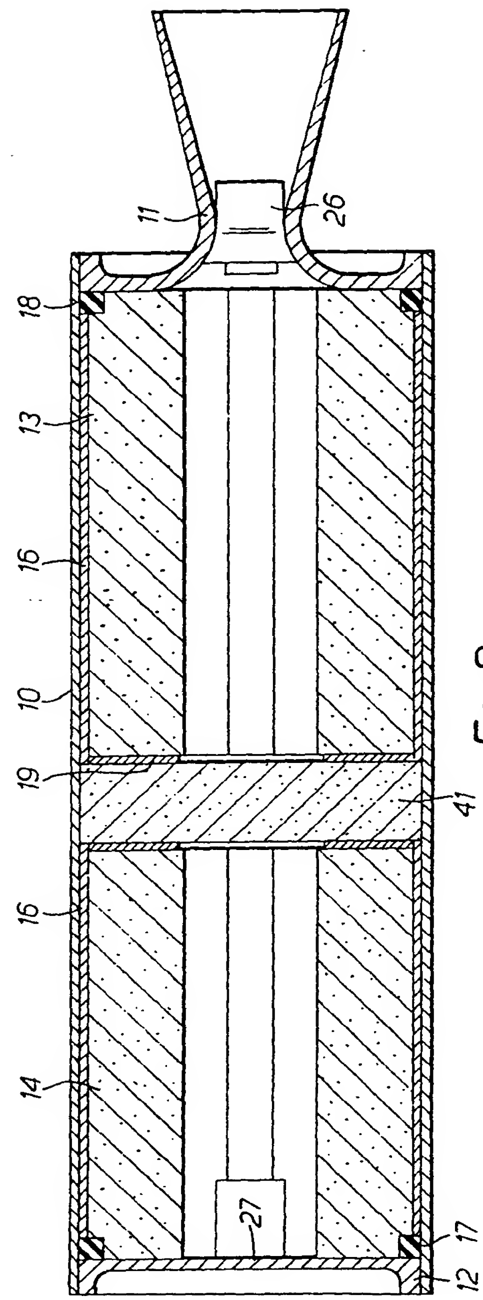

FIG. 8.